Managing the Gulf of Papua prawn fishery: sustainability, maximum returns and cooperation between commercial fishing and indigenous fishing communities

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In many fisheries around the world, harvesting capacity is excessive and fish stocks are under threat. The Gulf of Papua prawn fishery (GPPF) presents a different set of management challenges. Limited property rights and fishing capacity, along with tension between a commercial fleet and indigenous fishing communities over access, have resulted in a relatively underdeveloped resource, conflict and considerable losses in economic returns. This article details the results of a joint project between the National Fisheries Authority (NFA) in Papua New Guinea and supporting Australian institutions on the management of the GPPF. The analysis indicates a catch target that maximises sustainable returns at biomass levels larger than biomass at maximum sustainable yield, thus protecting the resource, and a simple plan to share access to the inshore fishery. Both strategies are being implemented by the NFA. Together, they present one of the few very good examples of how to 'get things right' in the use and management of a fisheries resource, providing 'win-win' outcomes for Papua New Guinea.

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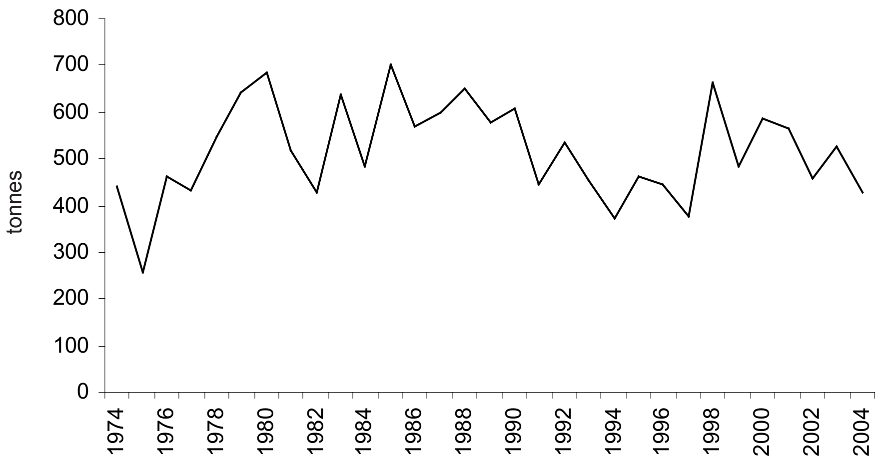
The management of limited-access fisheries is a difficult challenge. In most cases, the harvesting capacity of the fishing fleet exceeds the biological capacity of the resource to regenerate, threatening its viability. In other cases, insecure property rights and conflicts between commercial fishing interests and indigenous fishing communities result in the resource being under-utilised or poorly managed, with a loss in community profits and well-being. Ideally, management of the fishery should enhance economic performance and guarantee the biological and economic sustainability of fish stocks for generations to come at levels that maximise social returns.

The National Fisheries Authority (NFA) has the task of managing all fishery resources in Papua New Guinea. The tuna fisheries, shared with other Pacific island nations, are examples of the challenges facing fishery management. The evidence suggests a danger of over-fishing—with stocks of bigeye and yellow fin tuna at levels below stock at maximum sustainable yield (MSY)—and a clear loss in economic returns in these fisheries, with effort levels far greater than effort at maximum economic yield (MEY) (Kompas and Che 2006). The second most lucrative fishery in Papua New Guinea, the Gulf of Papua prawn fishery (GPPF) presents a different set of challenges. Here, limited property rights and fishing capacity, along with tension between a commercial fleet and indigenous fishing communities over access to an inshore fishery, have resulted in a relatively underdeveloped resource, conflict and considerable losses in economic returns.

With this concern in mind, the NFA and The Australian National University (ANU), in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Centre for International Agricultural Research (ACIAR), conducted a study of the economic performance and management of the GPPF between 2003 and 2006. The task of the joint NFA and CSIRO team was to construct logbook data and perform a stock assessment of banana prawns in the fishery. The joint ANU and NFA team assembled economic survey data and constructed and calibrated a bio-economic model of the fishery, based on the stock assessment, to indicate key management targets for optimal catch. In one of the first-ever examples of cooperation between economists, biologists and stock assessment scientists—at least in a developing country—both teams, in cooperation with a local management authority, provided recommendations to improve the management of the GPPF. Most recommendations have already been implemented, providing a good example of how to get things right in the use and management of a developing nation's fisheries resources.

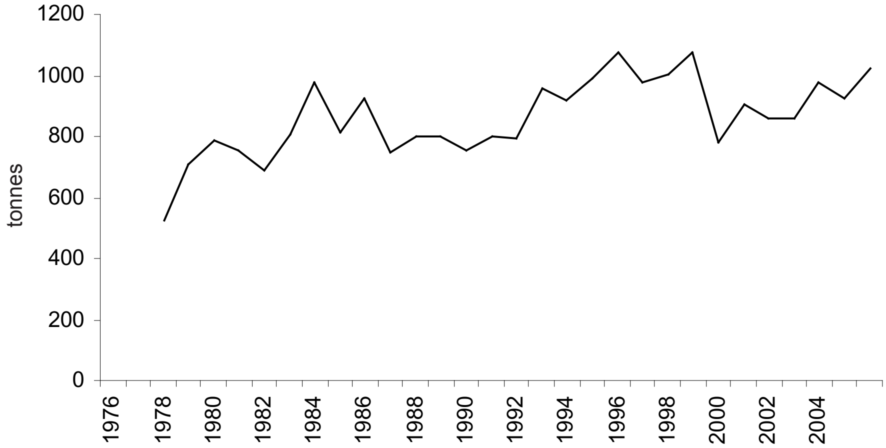
We provide an overview of the GPPF and then some background on the new

Figure 1 **Annual catch of banana prawns in the GPPF, 1974–2004** (tonnes)



Source: National Fisheries Authority (NFA), 2006a. *Biological Database and Stock–Recruitment Relationship for the Gulf of Papua Prawn Fishery*, National Fisheries Authority of Papua New Guinea, Port Moresby.

Figure 2 **Biomass estimates of banana prawns in the GPPF, 1976–2006** (tonnes)



Source: National Fisheries Authority (NFA), 2006a. *Biological Database and Stock–Recruitment Relationship for the Gulf of Papua Prawn Fishery*, National Fisheries Authority of Papua New Guinea, Port Moresby.

target for the fishery, MEY, as well as detail the bio-economic model used to set this target for the GPPF. Then we present an estimate of the harvest function and discuss the results, outlining major policy guidelines for the management of the fishery.

Overview of the Gulf of Papua prawn fishery

The GPPF lies west of Port Moresby, near Karima, and extends west to the mouth of the Fly River. Many species are caught but the main harvest is banana prawns, accounting for roughly half of Papua New Guinea's total prawn catch and more than 60 per cent of the gross value of production. Tiger and endeavour prawns are also caught. Historically, the harvest has been undertaken with 15 vessels, although recently increases in the price of fuel have reduced this number to less than ten. The catch of banana prawns from 1974 to 2004 averaged 517 tonnes per annum at an estimated average value of US$1.8 million. The catch has ranged from 258 to 700 tonnes (Figure 1). The fishery remains closed to foreign involvement. Prawns are processed and packed on board and exported mainly to Japan, Singapore and Australia, or are sold domestically. The fishery is managed under the GPPF Management Plan, under the direction of the NFA. Until recently, fishing entitlements were granted by the NFA to boat owners on a single-year lease basis.

Unlike many fisheries around the world, in the GPPF, estimates based on catch and effort data show that stocks of banana prawns are not under threat. If anything, given the recent fall in boats operating in the fishery, biomass has increased in the past few years (Figure 2), and has nevertheless been trending upwards over time.

This is a key result. Until this biomass series was constructed, there was considerable doubt about the sustainability of the prawn stocks in the GPPF, a doubt that in part explained the desire to constrain effort in the fishery and the reluctance on the part of the NFA to grant anything more than annual fishing licences (on a yearly lease basis). This limited property right makes it all but impossible for the commercial fishing industry to secure loans to upgrade vessels and conduct necessary continuing and long-term repairs and maintenance—a constant complaint among industry representatives. The fleet in the GPPF comprises boats more than 30 years old, obtained as cast-offs from the Australian northern prawn fishery (NPF), and more than one-fourth of variable costs go to maintenance and repairs. Breakdowns at sea are commonplace.

Finally, the GPPF is characterised by a highly productive inshore fishery within three nautical miles of the shoreline, which contains spawning grounds and is potentially accessed by indigenous communities who claim local fishing rights. This area is legally closed to the commercial fleet (the 15 boats that receive annual lease permits). Nevertheless, VMS and logbook data, compiled as part of the research effort in this project, showed that about one-third of the total prawn catch in the GPPF was coming from within this closed zone. This illegal accessing of the inshore waters (something long suspected) has been a source of great tension between the commercial fishing industry and traditional resource owners in the Gulf of Papua. Fortunately, the biological component of the project also showed that this illegal fishing did not appear to impact substantially on the sustainability of the prawn resource. From an economic perspective, however, catch rates within the three nautical mile zone were more than 30 per cent higher than from adjacent fishing grounds. For the most part, therefore, the economic viability of the fishery depends on operators in the commercial fishery accessing these inshore waters with higher prawn densities.

The bio-economic model and maximum economic yield

Based on relatively new insights (Grafton et al. 2007), the key economic target in fisheries management, the one applied in the GPPF, was MEY (Kompas 2005). Concentrating on sustainable yields alone, MEY occurs when the sustainable catch or effort level for the fishery as a whole maximises profits, or creates the largest difference between discounted total revenues and the total costs of fishing. For profits to be maximised, it must also be the case that the fishery applies a level of boat capital and other resources in combinations that minimise the costs of harvest at the MEY catch level. In other words, the fishery cannot be over-capitalised and vessels must use the right combinations of inputs such as gear, engine power, fuel, hull size and crew to minimise the cost of harvest at MEY (Grafton et al. 2006).

There are several points to note about MEY. First, for most practical discount rates and costs, MEY will imply that the equilibrium stock of fish is larger than that associated with MSY, providing a win-win situation for fisheries management in terms of larger fish stocks and maximum profits (Grafton et al. 2007). In this sense, the economic objective of MEY is more 'conservationist' than MSY and should in principle help protect the fishery from unforeseen or negative stochastic environmental shocks that could diminish the fish population. Second, the catch and effort levels associated with MEY will vary, as will profits, with a change in the price of fish or the cost of fishing. This is as it should be. If the price of fish increases, it pays to exploit the fishery more intensively, albeit at yields still less than MSY. If the cost of fishing rises, it is preferable to have larger stocks of fish and therefore less effort and catch.

Finally, as long as the cost of fishing increases with days fished and biomass decline, as it generally will, MEY as a target will always be preferred to MSY, and of course to any catch or effort level that corresponds with stocks that are smaller than those associated with MSY. The reasoning is simple: regardless of what happens to prices and costs, targeting catch and effort at MEY will always ensure that profits are maximised. Profits might be relatively low when the price of fish is low and the cost of fishing is high, but profits will still be maximised. With a biological target of MSY alone, however, it is quite possible that profits will be very small or even zero. The fishery would therefore be sustainable at MSY but would not be commercially viable, much less efficient.

Estimating MEY for the GPPF required constructing a bio-economic model; in other words, combining the stock assessment with key economic relationships in a dynamic context. This required

- a stock–recruitment relationship for the biology
- a harvest function, showing the relationship between effort, stock and catch, and
- measures of total revenues and costs.

Spawning stock–recruitment relationship

Surplus-production models, as a stock–recruitment relationship, map the relationship between the growth or net additions to the stock of prawns as a function of existing stock size, based on a known catch and effort series. The key parameters are the intrinsic rate of growth, r, and maximum carrying capacity. In a continuous-time model of population growth, without including fishing behaviour, a so-called Schaeffer surplus production model is given by

$$\frac{dB}{dt} = rB_t(1 - B_t / B_0) \qquad (1)$$

where B_t is the biomass of the stock at time t and B_0 is virgin biomass, or stock at time zero, defined as maximum carrying capacity. In discrete time, the relevant relationship is

$$B_{t+1} = \left[B_t + r\,B_t \left(1 - \frac{B_t}{B_0} \right)^z \right] (1 + e^{\xi_1}) - h_t \qquad (2)$$

where h_t is the catch rate and z is a parameter. The measure ξ_1 reflects uncertainty or randomness in the (biomass) stock–recruitment relationship in Equation 2. Harvest is generally assumed to be a function of the biomass and fishing effort at time t.

Harvest function

The harvest function at time t is given by

$$h_t = q^0 E_t^{\alpha}\ B_t^{\beta}\ (1 + e^{\xi_2}) \qquad (3)$$

where q^0 is an intercept, E_t is fishing effort at time t, B_i is biomass (or stock) at t and α and β are the parameters in the harvest function. The measure ξ_2 reflects uncertainty or the randomness in catch per unit of effort (CPUE) in Equation 3. From Equation 3, fishing effort is therefore given as

$$E_t = \left(\frac{h_t}{q^0 B_t^{\beta}} \right)^{1/\alpha} \qquad (4)$$

Total revenue function

Annual total revenue at time t, TR_t, is calculated as the multiple of harvest and the annual (average) price of each species of prawn, or

$$TR_t = h_t p_t \tag{5}$$

where p_t is the price of prawns at time t. In some cases, the price of prawns will depend on the amount of harvest; in others, the price is constant and determined on a world market for prawns. For the case of the GPPF, where most of the prawns are sold overseas, individual harvesters have little influence on price.

Fishing cost function

Fishing costs, including labour, material, repairs and maintenance, and all other costs, are generally assumed to be a function of fishing effort and stock. Fishing costs at time t, c_t, depend on a fixed-cost component and variable costs, which depend on fishing effort, E_t, or

$$c_t = \gamma_t^0 + \gamma_t^1 E_t \tag{6}$$

where γ_t^0 is a fixed-cost parameter and γ_t^1 is the variable cost share parameter. It is also assumed that γ_t^0 and γ_t^1 are positive. Substitution from Equation 4 for effort gives

$$c_t = \gamma_t^0 + \gamma_t^1 \left(\frac{h_t}{q^0 B_t^\beta} \right)^{1/\alpha} \tag{7}$$

in which the smaller the stock (or biomass), the larger is the cost of fishing.

Profit and objective functions

Annual fishery profit at time t, Π_t, is defined by subtracting annual total costs from annual total revenue, so that

$$\Pi_t = p_t h_t - \left[\gamma_t^0 + \gamma_t^1 \left(\frac{h_t}{q^0 B_t^\beta} \right)^{1/\alpha} \right] \tag{8}$$

The optimisation problem is to maximise aggregate profit over a period, T, through choice of the harvest, given by

$$\max_{h_t} \Pi_t = \sum_{t=0}^{T} \left(\frac{1}{(1+\delta)^t} \right) \left\{ p_t h_t - \left[\gamma_t^0 + \gamma_t^1 \left(\frac{h_t}{q^0 B_t^\beta} \right)^{1/\alpha} \right] \right\} \tag{9}$$

where δ is the discount rate. Solving Equation 9, subject to Equation 2, requires also that virgin biomass at time zero is known, or that it can be estimated. The optimal solution to Equation 9 establishes a catch value for MEY.

Analysis of MSY

The traditional management target, MSY, is obtained by solving Equation 2 for harvest, ignoring uncertainty (for the moment), so that

$$h_t = B_{t+1} - B_t + r B_t \left(1 - \frac{B_t}{B_0} \right)^z \tag{10}$$

At MSY, when biomass is constant over time, or when $B_{t+1} = B_t$, solving the variation

$$\frac{d\left[r\left(B_{MSY}{}^z - \frac{B_{MSY}{}^{z+1}}{B_0} \right)^z \right]}{dB_{MSY}} = 0$$

gives $zB_{MSY}^{z-1} = B_{MSY}^z (z+1) / B_0$, and a resulting measure of biomass at MSY, or

$$B_{MSY} = \frac{zB_0}{(z+1)} \tag{11}$$

with harvest at MSY, h_{MSY}, given by

$$h_{MSY} = \frac{rB_0}{(z+1)^{\frac{z+1}{z}}} \tag{12}$$

Estimates of the harvest function for the GPPF

A central component of the bio-economic model is the estimate of the harvest function, or the relationship between effort, stock (or biomass) and catch. A significant share parameter on the stock component indicates the presence of a 'stock effect', showing the importance of biomass on harvest and ultimately on the cost of fishing. Based on Equation 3, the econometric specification of the harvest function is given by

$$\ln h = \alpha_0 + \alpha_1 \ln E + \beta \ln B \qquad (13)$$

where h, E and B are harvest (in tonnes), fishing effort (in fishing days) and prawn biomass (in tonnes), respectively, and α_0, α_1 and β are parameters to be estimated. The value of α_0 is the log of q^0, for the intercept in Equation 3. Estimated results based on 27 annual observations between 1978 and 2004 are presented in Table 1. All variables are measured in log form.

Results and policy implications

To obtain results, the bio-economic model was parameterised, drawing from the biological and economic components of the research project. Key parameters in the biological model included a) a measure of biomass at maximum carrying capacity, B_0, of 1,300 tonnes; b) an intrinsic growth rate, r, of 1.956; and c) a value for z of one. The share parameters in the harvest function are given in Table 1. The main economic parameters, across more than 30 categories, were obtained from annual economic surveys carried out by the NFA. The main cost components included the cost of fuel, repairs and maintenance, gear, crew and material costs (NFA 2006b). Of these, repairs and maintenance and fuel costs are the most important, by far. The discount rate was assumed to be 5 per cent and the price of banana prawns was fixed at US$7.17 a kilogram. Final results for MEY (obtained through a coded procedure in *Maple*) and related target measures are given in Table 2.

The current harvest in the GPPF is 450 tonnes per annum. The results show that the calculated value of harvest at MEY is 580 tonnes, indicating that the fishery is underdeveloped. In order to maximise returns in the fishery, the harvest must increase. The value of the harvest at MEY is, however, smaller than the harvest at MSY, so the ratio of biomass at MEY to biomass at MSY is 1.23. This is important. Given the harvest function, it is clear that 'thicker

Table 1 **Estimate of the harvest function for the GPPF**

	Coefficient	SE	t	P>|t|
Dependant variable: harvest (tonnes)				
Effort (days)	0.47***	0.32	5.80	0.00
Biomass (tonnes)	0.42***	0.08	4.87	0.00
α_0	–0.09	0.08		0.79

*** indicates that the level of significance is 99 per cent. The adjusted R-squared is 0.83 and the F statistic is 62.74 (0.00). Diagnostic tests showed no serial correlation.
Source: Authors' estimations.

Table 2 **MEY results and target indicators for the GPPF**

Target/indicator	Value (tonnes)
Mean values at steady state	
Harvest at MEY	580
Biomass at MEY	800
Harvest at MSY	635
Biomass at MSY	650
Maximum carrying capacity	1,300
Current harvest (2006)	450
Current biomass (2006)	980
Ratio of BMEY to BMSY	1.23

Source: Authors' estimations.

stocks' result in larger profits, indicating a win-win for the environment and the fishing industry. In other words, having stocks of prawns larger than stocks at MSY, as a result of the MEY target, results in lower fishing costs, higher profits and a 'conservationist approach' to exploitable prawn biomass. Once implemented, this will be one of the few examples in the world, much less in developing countries, of the practical use of a fisheries target that maximises returns and protects fish stocks (Grafton et al. 2007). Alternatively, an MSY target, the traditional target in fisheries management, leads to relative losses, with no added increase in employment. The MEY target can be obtained with the current fleet and additional fishing time and capacity. Indeed, the loss in profits from harvest at MSY compared with harvest at MEY is estimated to be (on average) more than US$187,000 per annum. The MEY target is clearly preferable.

Several policy implications and management directives flow from this research, all of which the NFA is either implementing or pursuing actively. First, there need to be more secure fishing rights so that fishing capacity can be enhanced. The current harvest is less than the MEY target, and a reason for this is that the provision of annual leases to fish does not allow the industry to obtain finance for new vessels or upgrade gear or equipment, much less to cover standard and long-term repairs and maintenance. The NFA is moving to five-year leases, with the possible introduction of statutory fishing rights. Not only does MEY show that the target harvest should be larger than the current harvest, it shows that given the current fishing technology for prawns, MEY can be obtained with 10 or less standard prawn boats. In other words, the current fleet, when properly fitted and upgraded, should be sufficient to reach the MEY target. The fleet needs, however, the means to upgrade its fishing capacity. Concerns about stock size are not warranted and fishing entitlements can be extended.

The second main issue is access to the inshore fishery. As mentioned, research shows that about one-third of the total prawn catch by the commercial fleet comes from this zone, even though such fishing is prohibited. Fortunately, given this 'natural' (albeit illegal) experiment, the biological component of the research project showed that the inshore fishing did not appear to impact adversely on the sustainability of the prawn resource. The economics of the inshore fishery is, however, critical. Catch rates are more than 30 per cent higher in this zone, adding considerably to profits, and without access to the inshore area by the commercial fleet, the target MEY will not be reached. To allay the tension between indigenous owners of the inshore areas and the commercial fleet, the research team recommended that the commercial fleet be allowed to access the inshore zone up to two nautical miles from the coast (to protect spawning areas) during the second half of the fishing year (or from July to November), based on an access agreement with the traditional resource owners. This recommendation has been well received by all stakeholders, and has provided a potential win-win for indigenous owners and the commercial industry, which is now negotiating precise access rights and amounts. The research project recommended a simple sharing of net profits (or at least a proportion of catch) in the inshore fishery, with percentage shares to be determined by use and the extent of participation in fishing by the industry and the traditional owners. This resource sharing will enable some of the economic benefits gained by the industrial fishery to be returned to the community and will therefore reduce the tension between the parties. It will also allow the commercial fleet to access the highly productive inshore area more intensively, to meet MEY.

The final management concern is the catch composition of prawns. MEY is the right target catch level, but the GPPF still lacks the right management instrument. Setting the catch level without allocated fishing rights—for example, individual tradeable quotas—does not prevent 'race to fish' behaviour. As a result, fishers do not delay the catch until prawn size and economic value increase; rather, small prawns are taken and returns suffer. The provision of a guaranteed share of catch would allow vessels to time catches with optimal prawn size. Unfortunately, tradeable quota systems are costly to implement and monitor and are undoubtedly beyond the reach of NFA resources at this time. Nevertheless, given the small number of operators in the fishery, an agreement on catch timing is possible, and is indeed under some discussion.

Final remarks

The GPPF provides only the second example in the world of a fishery that uses an MEY target; the NPF in Australia is the first. An MEY target has two clear advantages: it maximises returns in the fishery and protects fish stocks. It is a good example of how to get things right in fisheries management, at least in terms of the right target and a 'healthy' stock of fish, and its application is especially noteworthy in this case given that the GPPF is a developing-country resource. The GPPF has the advantage of not being over-exploited to begin with, so that rather than undergoing the painful process of industry restructuring to rebuild stock to obtain MEY, the NFA has only to provide conditions conducive to increasing fishing capacity. This can be done with the current fleet size and, indeed, reaching MEY catch levels will increase profits and maintain, if not increase, employment levels. Cooperation between the commercial fleet and the indigenous owners of the inshore fishery ensures added profitability and the sharing of gains from this productive area. Both of these actions—establishing the right target and ensuring sound cooperation between relevant stakeholders—provide welcome win-win outcomes for Papua New Guinea.

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